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^{40}Ar-^{39}Ar age analyses of some intruded rocks from Mt. Riiser-Larsen in the Napier Complex

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Abstract: Three ^{40}Ar-^{39}Ar geochronological studies are performed for intruded rocks from Mt Riiser-Larsen in the Napier Complex, East Antarctica All samples have excess Ar and no ^{40}Ar-^{39}Ar plateau ages are obtained from these results Considering two previous age results, however, two metamorphic events at about 700-750 Ma and 1000-1100 Ma might have been suggested

key words ^{40}Ar-^{39}Ar age, Mt Riiser-Larsen, Napier Complex

1. Introduction

^{40}Ar-^{39}Ar age studies have been reported for two gneisses and two dykes from Mt Riiser-Larsen in the Napier Complex, East Antarctica (Takigami *et al*, 1998) The ages of dykes are about 800-1100 Ma and similar to the Rb-Sr age (1190±200 Ma) of the Amundsen dyke (Sheraton and Black, 1981)

A geological team of the summer party of the 38th Japanese Antarctic Research Expedition collected additional dyke samples from Mt Riiser-Larsen (Fig 1) and paleomagnetic studies have been performed on these samples (Ishikawa and Funaki, 2000) ^{40}Ar-^{39}Ar age studies have been tried on these samples in order to check whether the same age results as the previous ^{40}Ar-^{39}Ar results by Takigami *et al* (1998) are obtained or not

2. Experiments

Samples A and B were collected from sites A and B about 5-7 km east from sites 5 and 7 from which ^{40}Ar-^{39}Ar ages have been found to be about 800-1100 Ma (Takigami *et al*, 1998) (Fig 1) Sample 6 was collected from a site adjacent to sample 7 (Fig 1) Paleomagnetic studies for these samples have been reported in Ishikawa and Funaki (1997, 1998, 2000) All samples are metadolerite and have been classified into four types on the basis of chemical compositions by XRF analyses (Ishizuka and Suzuki, 1999) Types-A and -B are alkaline types, the Nb/Zr ratio is different between types-A and -B Types-C and -D are non-alkaline types and have different abundance in Nb and Zr Types of samples of sites A and B, site 6 and site 7 are -B, -D and -A, respectively The type of

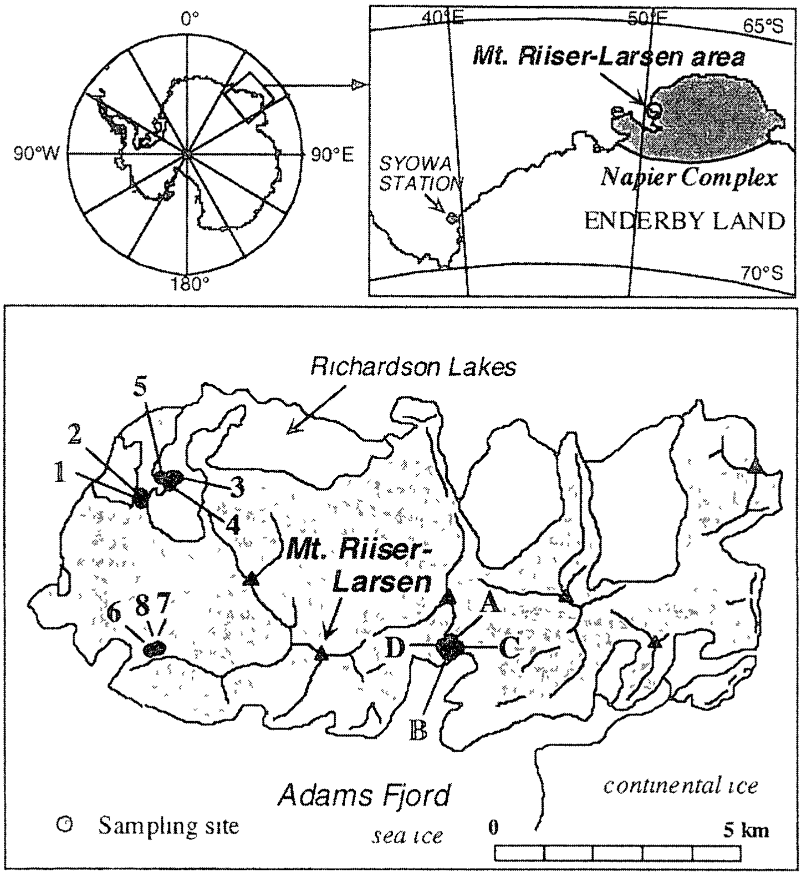


Fig 1 Sampling sites for samples 5, 6, 7, A and B (after Ishikawa and Funaki, 2000)

sample 5 is not determined

These samples were crushed and sieved from 30 to 60 mesh After washing by acetone, they were wrapped in Al foil and packed in a quartz tube under vacuum condition with age standard samples (EB-1, biotite separated from JG-1, 91 4±0 5 Ma (Iwata, 1998)) and chemical samples (K_2SO_4 and CaF_2) used for the correction of interference Ar isotopes They were irradiated by fast neutrons of about 10^{18} neutrons/cm^2 for 24 hours at the JMTR (Japan Material Testing Reactor)

After Ar gas was extracted from each sample using an induction heater and purified with Ti getters, isotopes of Ar were analyzed by a mass spectrometer, VG3600 (Micromass) Ages are calculated after correction for mass discrimination and interfering isotopes derived from K and Ca Detailed experimental procedures and formulas are written in Takigami *et al* (1998) and McDougall and Harrison (1999)

3. Results and Discussions

Results are shown in Table 1 and Fig 2 A large error of 1100°C fraction of sample A is an experimental error As a meaningless result is obtained for isochron plots due to the scattered data, these isochron figures are not shown

Age spectra of these samples are extremely similar The U-shape is typically recog-

Table 1 Analytical data of ^{40}Ar-^{39}Ar studies

Sample A (0 0682g, J=0 003224±0 000019)

Temperature (°C)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-5}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{38}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-5}$)	$^{40}Ar^*/^{39}Ar_K$ [(1)]	$^{39}Ar_K$ (%)	Age[(2)] (Ma)	K/Ca[(3)]
500	12 4	2 915	0 5935	0 144	9 866	10060	0 30	6331	1 661
		±0 064	±0 0146	±0 0021	±1 343	±1369		±239	
600	6 64	2 024	1 579	0 289	42 47	2342	0 69	3871	2 689
		±0 089	±0 032	±0 0042	±0 34	±19		±16	
700	5 81	1 993	5 506	0 871	140 0	710 3	1 99	2149	2 542
		±0 096	±0 109	±0 011	±1 0	±5 1		±12	
800	8 53	2 848	7 467	2 720	449 7	220 5	9 41	968.7	6.022
		±0 091	±0 150	±0 030	±3 2	±1 6		±6.9	
900	10 7	n d [(4)]	10 40	3 762	632 8	158 0	16 57	742.7	6 082
			±0 21	±0 041	±1 5	±0 4		±3 9	
1000	11 5	0 1341	16 37	3 230	539 0	185 5	15 13	845 6	3.292
		±0 0647	±0 32	±0 036	±1 2	±0 4		±4 3	
1100	8 24	n d	33 56	3.106	427 1	234 3	8 61	1015	1.271
			±5 41	±0 523	±71 5	±39 3		±130	
1200	15 9	n.d	31 74	2 291	344 9	290 2	13 41	1192	1 086
			±0.63	±0 026	±0 9	±0 8		±6	
1300	17 4	n d	80 78	1 700	271 7	369 5	30 68	1415	0 3351
			±1 58	±0 020	±0 9	±1 2		±7	
1400	5 21	n d	145 5	1 393	252 1	399 8	3 20	1494	0 1720
			±2 8	±0 020	±0 6	±0 9		±7	

Table 1 Continued

Sample B (0 0684g, J=0 003224±0 000019)

Tempe-rature (℃)	^{40}Ar (× 10^{-6} cm^3/g)	^{36}Ar/^{40}Ar (× 10^{-5})	^{37}Ar/^{40}Ar (× 10^{4})	^{38}Ar/^{40}Ar (× 10^{-4})	^{39}Ar/^{40}Ar (× 10^{-5})	^{40}Ar*/ ^{39}Ar$_K$	^{39}Ar$_K$ (%)	Age (Ma)	K/Ca
500	26 9	0 7632	0 2670	0 02018	1 437	69500	0 11	9772	0 5379
		±0 0377	±0 0119	±0 00444	±0 535	±25920		±670	
600	9 64	n d	1 537	0 2247	40 24	2486	1 10	3967	2 617
			±0 0348	±0 0036	±0 32	±20		±16	
700	6 30	n d	4 810	0 6120	105 6	947 7	1 88	2526	2 193
			±0 097	±0 0080	±0 8	±6 8		±13	
800	10 4	1 186	11 62	2 324	390 4	255 2	11 54	1083	3 358
		±0 056	±0 23	±0 025	±2 8	±1 8		±8	
900	14 5	0 4169	8 166	2 959	501 8	199 0	20 63	894 2	6 143
		±0 0463	±0 162	±0 032	±3 6	±1 4		±6 6	
1000	17 9	0 2543	10 90	2 253	373 6	267 5	18 99	1122	3 426
		±0 0391	±0 21	±0 024	±2 7	±1 9		±8	
1100	20 2	0 0209	20 51	2 125	294 9	339 4	16 90	1333	1 436
		±0 0703	±0 48	±0 031	±2 7	±3 1		±10	
1200	19 3	n d	35 77	1 747	267 6	374 3	14 63	1428	0 7469
			±0 71	±0 020	±2 1	±2 9		±10	
1300	18 7	0 4999	81 04	1 419	241 4	415 6	12 72	1534	0 2860
		±0 064	±1 66	±0 016	±1 7	±3 0		±10	
1400	2 64	3 935	73 91	1 240	203 2	488 9	1 51	1707	0 2736
		±0 329	±1 47	±0 019	±1 7	±4 0		±11	

Sample 6 (0 0644g, J=0 003224±0 000019) *Table 1 Continued*

Temperature (℃)	^{40}Ar ($\times 10^{-6}$ cm^3/g)	$^{36}Ar/^{40}Ar$ ($\times 10^{-5}$)	$^{37}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{38}Ar/^{40}Ar$ ($\times 10^{-4}$)	$^{39}Ar/^{40}Ar$ ($\times 10^{-5}$)	$^{40}Ar^*/^{39}Ar_K$	$^{39}Ar_K$ (%)	Age (Ma)	K/Ca
500	1 21	72 03	25 93	1 426	32 38	2456	0 82	3948	0 1236
		±1 35	±0 54	±0 027	±0 29	±26		±19	
600	1 03	49 34	39 14	1.095	50 17	1720	1 07	3390	0.1269
		±1 21	±0 78	±0 028	±0 42	±16		±17	
700	0 955	46 31	80 71	1 367	101 4	860 7	2 01	2396	0 1243
		±1 31	±1 61	±0 034	±0 9	±8.3		±15	
800	1 31	58 21	149 1	2 619	290 7	286 9	7 92	1181	0 1937
		±1 26	±2 9	±0 043	±2 1	±2 5		±9	
900	2 35	24 19	161 8	2 400	341 1	274 0	16 73	1142	0 2096
		±0 64	±3.2	±0 032	±2.5	±2 1		±8	
1000	3 30	16 03	247 2	2 197	330 2	291 6	22 65	1196	0.1322
		±0 47	±4 8	±0 030	±2 4	±2 2		±8	
1100	3 59	14 10	290 4	2 001	294 7	329 8	21 87	1307	0 1002
		±0 45	±5 7	±0.026	±2 2	±2 5		±9	
1200	3 54	5 653	152 8	1 332	210 4	472 1	15 46	1669	0 1364
		±0 395	±3 0	±0 019	±1 5	±3 5		±10	
1300	4 07	13 40	261 8	0 8812	104 1	955 0	8 59	2536	0.03846
		±0 44	±5 2	±0 0146	±0 8	±7 9		±14	
1400	2 83	24 43	487 8	0 7284	54 83	1915	2 88	3555	0 009960
		±0 73	±9 6	±0 0155	±0 51	±22		±20	

± in values are errors of one standard deviations

^{36}Ar, ^{37}Ar, ^{39}Ar and ^{40}Ar in this table are not corrected for interfering isotopes derived from K and Ca

Ages and $^{40}Ar^*/^{39}Ar_K$ values are corrected for interfering isotopes by using the following data,

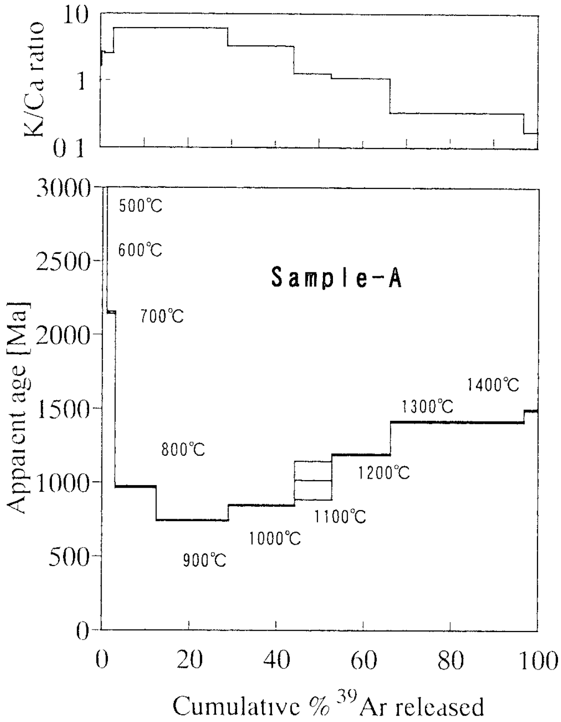
$(^{40}Ar/^{39}Ar)_K=(9\ 264\pm0\ 339)\times10^{2}$, $(^{39}Ar/^{37}Ar)_{Ca}=(1\ 280\pm0\ 027)\times10^{3}$, $(^{36}Ar/^{37}Ar)_{Ca}=(1\ 774\pm0\ 356)\times10^{4}$

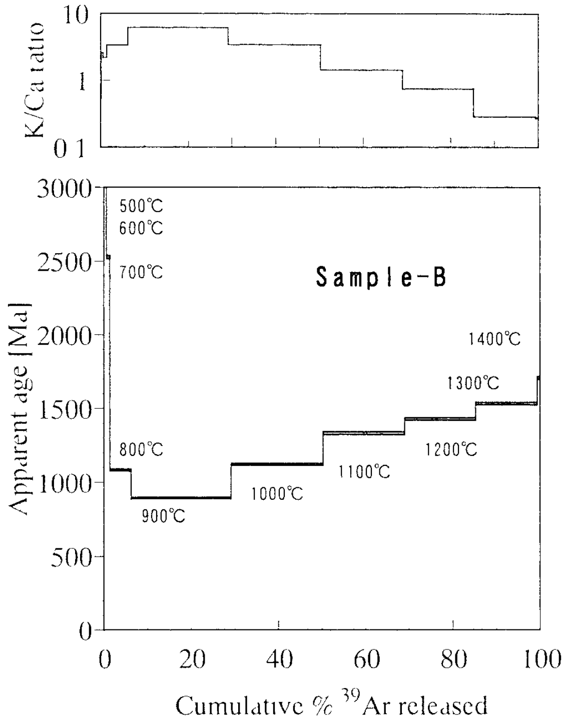
(1) $^{40}Ar^*$ and $^{39}Ar_K$ mean the radiogenic ^{40}Ar and K-derived ^{39}Ar, respectively

(2) Ages are calculated by using the following constants $\lambda_e=0\ 581\times10^{10}/y$, $\lambda_\beta=4\ 962\times10^{10}/y$,

$^{40}K/K = 1\ 167\times10^{4}$ (Steiger and Jager, 1977)

(3) K/Ca ratios are calculated from $^{39}Ar_K/^{37}Ar_{Ca}$, where $^{37}Ar_{Ca}$ means Ca-derived ^{37}Ar (4) "n d " means "not detected"





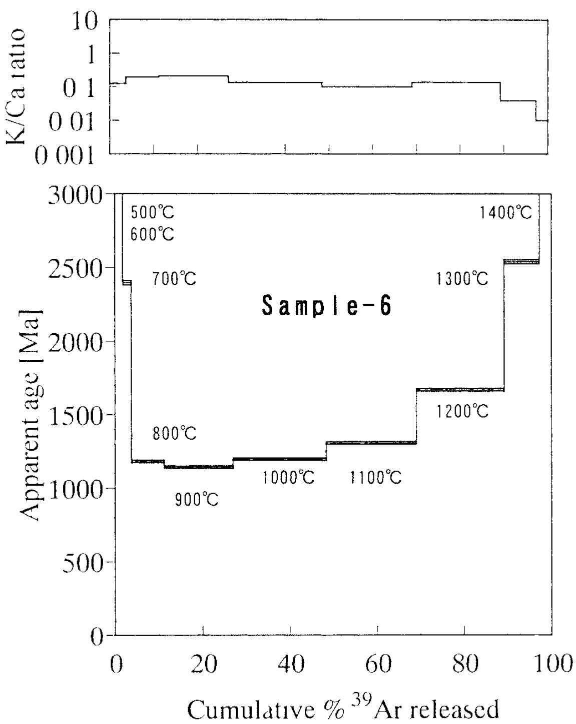


Fig 2 *^{40}Ar-^{39}Ar age spectra and K/Ca plots for samples A, B and 6 The upper part is a K/Ca plot and the lower part is an age spectrum for each sample The variation of K/Ca ratios indicates the Ar gas degassed from different sites or minerals in the sample Errors are the standard deviation and mostly included in the age bands in the age spectrum and not illustrated in the K/Ca plot*

nized for the pattern of excess Ar (McDougall and Harrison, 1999), which is recognized from extreme old ages, such as 6000 Ma, in lower temperature fractions The minimum age at the 900°C fraction and the stair-case pattern from 900°C to higher temperature fractions suggest the degassing of Ar gas by the metamorphism Moreover, the fractions of the minimum ages are only 900°C fractions with only 17–23% of released ^{39}Ar Then,

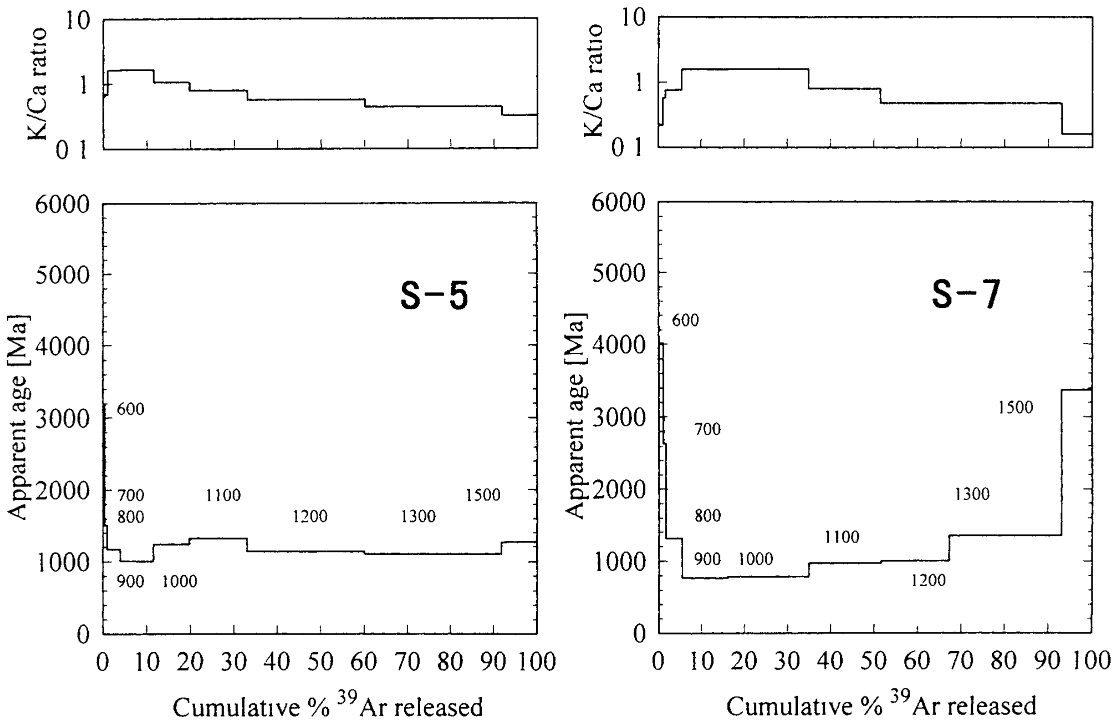


Fig 3 ^{40}Ar-^{39}Ar age spectra and K/Ca plots for samples 5 and 7 (after Takigami et al, 1998) Captions are the same as in Fig 2 Numerical figures represent the Ar degassing temperatures in Celsius degrees (°C)

the minimum ages do not represent the original ages of these samples and are difficult to consider as the true metamorphic ages The metamorphic ages may be younger than the minimum ages, 743 Ma (Sample A), 894 Ma (Sample B) and 1142 Ma (Sample 6)

As previous samples of 5 and 7 are also dolerite dykes in Mt Riiser-Larsen, our discussion will include these samples Age spectra and K/Ca ratios of samples 5 and 7 are also shown in Fig 3 Moreover, rock types, striking directions and ^{40}Ar-^{39}Ar minimum ages of dyke samples used in this study are summarized in Table 2

Sample 6 and sample 5 have minimum ages of 1005–1142 Ma and samples 7, A and B have young minimum ages of 743–894 Ma (Table 2)

Suzuki *et al* (2000) has reported a Sm-Nd age of 1912±169 Ma as an original age for type-D dyke samples that are the same rock type as sample 6 Accordingly, the minimum age of 1142 Ma (900°C) of sample 6 may suggest that the type-D samples had been metamorphosed at younger than 1142 Ma

As the age spectrum of sample 5 represents a relatively plateau-like pattern and there is a Rb-Sr age of 1190±200 Ma for the Amundsen dyke (Sheraton and Black, 1981), there is a possibility that the age of about 1000–1100 Ma of 900–1300°C of sample 5 represents the time of igneous activity of this dyke However, considering the result of sample 6 and the geological evidence of the intense shear at the site of sample 5 (Ishizuka *et al*, 1998), the plateau-like age of sample 5 (1000–1100 Ma, 900–1300°C) may represent the metamorphic age of about 1000–1100 Ma

A Rb-Sr age of 1233±384 Ma has been reported as an intrusion age for another dyke of type A (Suzuki *et al*, 2000) As this age covers 1000–1100 Ma, this dyke intrusion

Table 2 Summary of dyke samples and ^{40}Ar-^{39}Ar minimum ages

Sample (Site)	Direction from Mt Riiser-Larsen	Rock type(1)	Striking direction	Age spectrum pattern	Minimum age (Ma)	Remarks
5	NW	-	N24 5° E	Plateau-like	1000-1100(2)	Intense shear (3)
6	W	D	N36 5-44 5° E	Excess	1142	1912±169 Ma (Sm-Nd age of type-D) (4)
7	W	A	N43 5° W	Excess	765(2)	1233±384 Ma (Rb-Sr age of type-A) (4)
A	E	B	N15 5° E	Excess	743	
B	E	B	N15 5° E	Excess	894	

(1) Ishizuka and Suzuki, 1999, Type-A and -B are the alkaline type, and type-C and -D are the non-alkaline type

(2) Takigami *et al*, 1998

(3) Ishizuka *et al*, 1998

(4) Suzuki *et al*, 2000

might have metamorphosed samples 5 and 6 at the same time

The minimum age (765 Ma) of sample 7 may suggest the existence of another metamorphic event at younger age than it from following reasons, i) the stair-case pattern is recognized in the age spectrum, ii) there is a Rb-Sr age (1233±384 Ma) for dykes of the same rock type to sample 7 (Suzuki *et al*, 2000), iii) this is the dyke sample which may have cooled not slowly after the intrusion The minimum ages of sample A (743 Ma) and sample B (894 Ma) support this metamorphic event And, as the Rb-Sr age had been preserved, it seems that the metamorphic event had not been intense

Moreover, the CHIME age of about 700 Ma, which is similar to the ^{40}Ar-^{39}Ar minimum ages, has been reported for pegmatites from Khmcra Bay, about 100 km SW from Mt Riiser-Larsen, in the Napier Complex (Grew *et al*, 2001) This result might suggest that the metamorphism occurred widely at about 700–750 Ma to the south or southwest of Mt Riiser-Larsen

As samples 7, A and B are alkaline type rocks and sample 6 is a non-alkaline type rock (Table 2), the metamorphic ages of about 700–750 Ma and 1000–1100 Ma might correspond to the rock types of alkaline and non-alkaline, respectively

Though sample 7 and sample 6 were collected from adjacent sites (Fig 1), they have different minimum ages As the metamorphism of sample 7 seems to have taken place at about 700–750 Ma, it may be reasonable that sample 6 has a similar minimum age of about 750 Ma The different minimum ages between sample 7 and sample 6 might be due to the difference in rock types, alkaline or non-alkaline

4. Summary

^{40}Ar-^{39}Ar age results indicate the possibility of two metamorphisms at about 700–750 Ma and 1000–1100 Ma for dyke samples in the Mt Riiser-Larsen area However, as Ishizuka and Suzuki (2000a, b) suggested the existence of 4 types of magmas and various metamorphisms in this area from the rare earth element compositions and the constituent minerals of dykes, we need more ^{40}Ar-^{39}Ar studies for dyke rocks in order to clarify the detailed history of dyke intrusions and metamorphisms in the Mt Riiser-Larsen area

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